Chapter 5

Hip Fracture: Anatomy, Causes, and Consequences

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Abstract

Fall-induced hip fracture is a major worldwide health problem among the elderly population. Nowadays, hip replacement surgery represents a big part of the orthopedic surgeons' workload and has associated remarkable clinical and social cost implications. Hip fractures have several complications including medical and surgical treatment. A significant number of biomechanical models have been introduced to study hip fracture risk. The purpose of proposing the biomechanical models for predicting the hip fracture risk is to introduce prevention and protection activities that may reduce the number of hip fractures. For accurate prediction of hip fracture risk, the fracture procedure and the parameters that affect the risk of hip fracture should be well studied. The objective of this study is to investigate in-depth the hip fracture anatomy, causes, and consequences.

Keywords: hip fracture causes, hip anatomy, fall, hip impact force, hip fracture consequences

1. Introduction

Low-trauma hip fracture has become a common health problem among the elderly all over the world [1–21], mainly due to the population aging and the prevalence of osteoporosis. Of all osteoporotic fractures, hip fracture has the highest morbidity and mortality rate [22]. Approximately 50% of patients have permanent functional disability greater than that before fracture [23, 24]. The incidence of hip fracture appears to be increasing in many countries [10], and the total number of hip fractures is estimated to be more than five million by 2050 [25]. Socioeconomic impacts of hip fracture are twofold. On the one hand, hip fracture increases the morbidity and mortality in the elderly [26–28]; on the other hand, it is a substantial source of healthcare expenditure [29, 30]. Therefore, there is an urgent need to accurately assess hip fracture risk and then develop preventive and protective measures. In this chapter, hip anatomy is first reviewed, and hip fractures are classified by anatomic location. Then, prevalence of hip fracture is presented, followed by a description of the significance of accurately assessing hip fracture risk.

2. Hip fracture anatomy

Hip fracture is a medical condition in which there is a break in the continuity of the femoral bone. Hip fracture is generally affected by hip anatomy [31], the applied forces to the hip [32], and bone mechanical properties [33]. In this section, hip anatomy is explained to show why the hip is likely to experience fracture in a fall.

The hip joint is one of the most important joints in the human body. It is also one of the most flexible joints allowing a great range of motions. To better understand hip fracture, it helps to know the anatomy of the hip joint. The hip is a joint formed by the ball-shaped head of the femur and the socket of the pelvis. The femurs are the longest and the strongest bones in the human body, extending from the hip to the knee. Important geometric features of femur bones include the head, neck, and greater and lesser trochanters, as shown in **Figure 1(a)**. A femur is composed of two types of bones, cortical and cancellous. The cortical bone forms the outer layer of the femur and withstands most of the forces and moments. Cancellous bone is mostly enclosed by the cortical bone and mainly absorbs the shock energy produced in walking and running [34]. The hip joint is a stable ball-and-socket joint, much more stable than the shoulder joint. The stability in the hip mainly attributes to the deep socket, i.e., the acetabulum. Additional stability is provided by the strong joint capsule and its surrounding muscles and ligaments. The high level of stability of the hip joint is required to support the upper body [34].

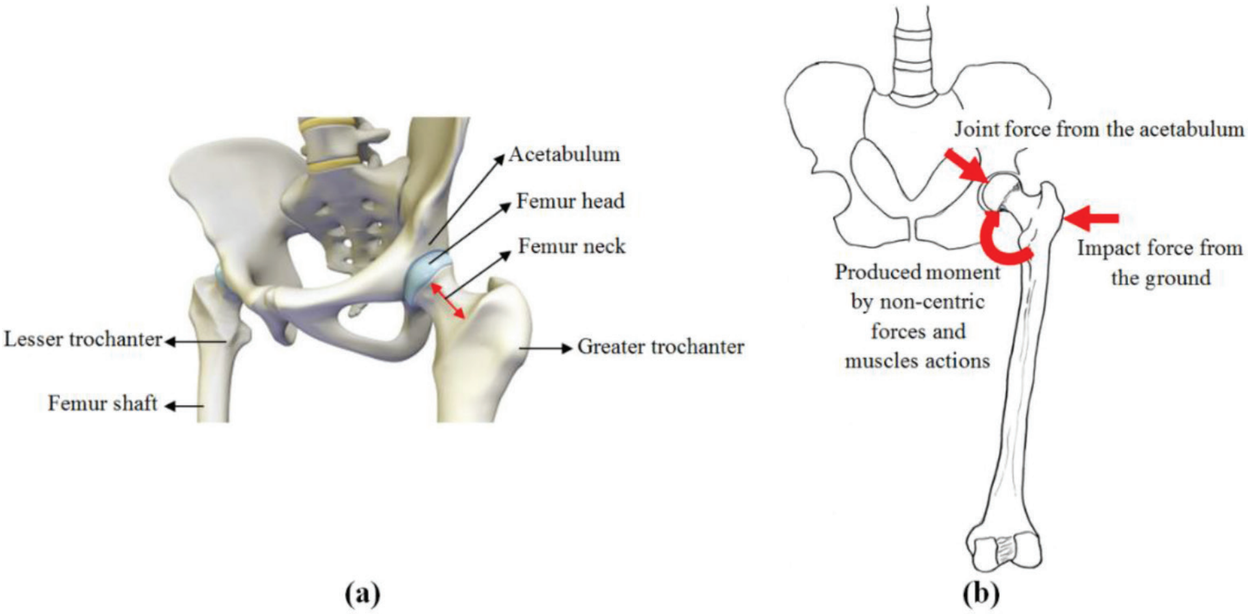

Figure 1. (a) Anatomic structure of the hip [35]. (b) Concentration of applied forces on the proximal femur in a lateral fall which increases the risk of fracture.

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More than 90% of all hip fractures occur in falls [36] as the femur is subjected to a high-level impact force. As shown in **Figure 1(b)**, in a sideways fall, the greater trochanter and the femoral head are subjected to the impact and the joint force, respectively, from the ground and the acetabulum. The forces produce a moment at the intersection of the neck-shaft axes. Muscles that are attached to the femur also produce forces during the fall. As it is shown in **Figure 1(b)**, the applied forces in a fall are mainly on the proximal femur, and it may explain why the majority of fall-induced hip fractures occur at the proximal femur [37]. A hip fracture refers to any fracture of the proximal femur down to a level of approximately 5 cm below the lower border of the lesser trochanter [38]. The extent of the break depends on the forces that are involved.

3. Hip fracture causes

Hip fracture is usually caused by an applied force that exceeds the strength of the femur bone [39]. Therefore, any situation that either induces a high level of force on the femur bone or decreases the bone strength should be considered as a hip fracture cause.

The main cause of hip fracture is falling (90–92%) [36, 40–42], in particular falling in sideways direction (63–69% in fall-related fractures) [8, 43], as it induces a high level of force on the femur. Parameters that increase the risk of fall and apply a high level of force on the femur, especially in the elderly, are:

- Mental impairment and confusion
- Impaired vision
- Impaired muscle reactions
- Slow reflex response
- Inability to effectively use the arms to reduce the energy of the fall
- Impaired neuromuscular coordination and neurological diseases (e.g., hemiplegia, Parkinson’s disease)
- Reduced soft tissue padding over the hip [44, 45]

In the elderly, most fractures occur after a low-trauma fall, which would not cause any severe injury to a healthy individual. Therefore, low bone strength is another main cause of hip fracture. Osteoporosis as a progressive bone disease, which is characterized by decreases in bone mass and density, has been identified as one of the main contributors of hip fracture [46, 47]. Osteoporosis advances when bone resorption exceeds bone formation, and therefore it is more common among the elderly [48]. Approximately three to four out of ten women over the age of 50, and one in eight men, suffer osteoporotic fracture in their lifetime [49].

Apart from osteoporosis, several other causes may reduce the strength of the bone such as bone cancer and medical side effects [38]. Other factors associated with reduction in bone strength include [38]:

- Genetic and family history
- Sedentary lifestyle
- Impaired nutrition
- Smoking
- Excess alcohol
- Medications (including tranquilizers, hypnotics, anticonvulsant drugs, and steroids)
- Osteomalacia from vitamin D deficiency, malabsorption, and liver or renal disease
- Cardiovascular disease and cardiac arrhythmias
- Underlying bone disease (e.g., Paget's disease, bone tumors, and secondary bone tumors)
- Endocrine abnormalities: hyperthyroidism, hyperparathyroidism, or hypercortisolism

In addition to the mentioned causes, high-trauma falls and accidents such as car and motorcycle accidents can lead to hip fracture [50]. But they are not studied in this dissertation. **Figure 2** shows how different factors contribute to the hip fracture [6, 38].

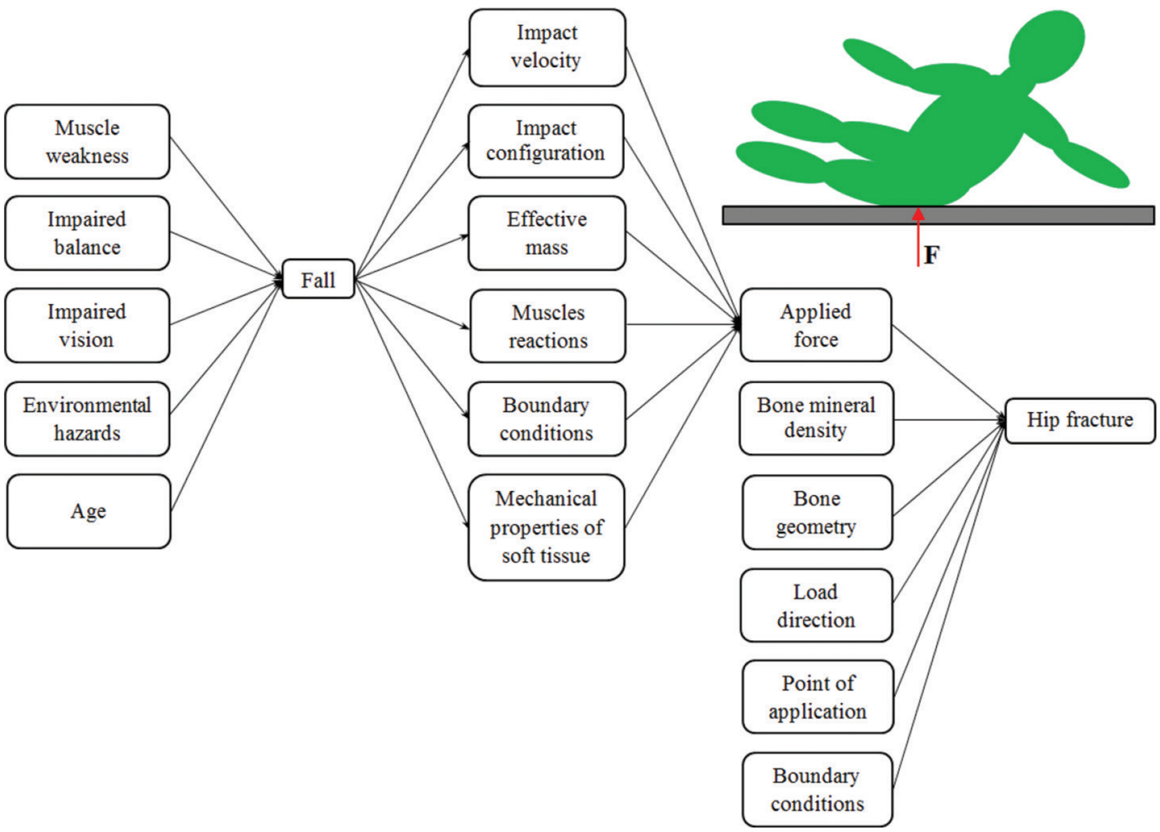

Figure 2. Conceptual model of the fall-induced hip fracture procedure and associated effective factors [15].

4. Hip fracture consequences

Hip fractures are associated with significant morbidity, mortality, loss of independence, and financial burden [3, 9, 25, 42, 51–53]. It has been reported that approximately 20% of hip fracture patients died within 1 year of the fracture [54]. Generally, the first year after hip fracture appears to be the most critical time. A recent meta-analysis revealed that women sustaining a hip fracture had a fivefold increase and men almost an eightfold increase in relative likelihood of death within the first 3 months compared with age- and sex-matched controls [29]. The relative death risk decreases substantially over the second year but still much higher than that of the controls [55]. Many lose their ability to walk mainly due to the pain caused by the hip fracture. In fact, only 40–79% of patients regain their previous ambulatory function a year after the fracture, and less than half return to their pre-fracture status of daily activities [56].

In addition to functional impairments, hip fracture can have a negative impact on self-esteem, body image, and mood [57], which may lead to psychological problems [58]. Individuals who suffer fractures may be immobilized by a fear of falling again and suffering more fractures. They may feel isolated and helpless. The National Osteoporosis Foundation conducted a survey [59] among 1000 women with osteoporotic fracture in the United States to investigate the psychological effects of the fracture on the patients. Eighty-nine percent of said they feared breaking another bone; 80% were afraid that they would be less able to perform their daily activities and lose their independence; 73% worried that they would have to reduce activities with family and friends; and 68% were concerned that another fracture would result in their having to enter a nursing home [59]. If not addressed, fear about the future and a sense of helplessness can produce significant anxiety and depression. These problems may be compounded by an inability to fulfill occupational, domestic, or social duties, thus leading to further social isolation.

The disability, reduced functional status, and poor mental health caused by hip fracture can have a profound impact on the quality of the individual's life. Survivors of hip fracture reported a 52% reduction in the quality of life in the first 12 months and a 21% reduction after 2 years [60].

Also, hip fracture is a major cause of the need for long-term nursing home care and a major contributor to healthcare costs [30, 61, 62]. There are approximately 23,000 cases of hip fracture every year in Canada with associated treatment costs of about $1 billion [63]. In the United States, 310,000 hip fractures occurred in 2003, and the total Medicare cost was estimated between $10.3 and $15.2 billion, including acute medical care and nursing home services [53, 64, 65]. As the population of the elderly is still continuously increasing, the number of hip fractures is expected to rise dramatically, and it will put more burdens on the community healthcare system [2, 66].

5. Classification of hip fractures

In general, there are three types of hip fractures, depending on what region of the proximal femur is involved [67]:

1. Femoral neck fractures occur in the narrow section of the proximal femur that lies between the femoral head and the intertrochanteric cross section. Most femoral neck fractures occur within the capsule surrounding the hip joint and are, therefore, termed intracapsular fracture. The blood supply to the femoral head is carried by a number of arteries that pass through the femoral neck region. Therefore, femoral neck fractures may disrupt the blood supply to the femoral head, causing death of the femoral head bone tissues, called osteonecrosis or avascular necrosis. Femoral neck fractures are further grouped into nondisplaced and displaced fractures by the alignment of the fractured segments in relation to the original anatomic position of the femur [68].

2. Intertrochanteric fractures occur at a lower location than femoral neck fractures, in the area between the greater and lesser trochanters. The trochanters are bony projections where major hip muscles are attached. Intertrochanteric hip fractures occur outside of the joint capsule and are therefore also called extracapsular fracture in the literature. Intertrochanteric fractures are complicated by the pull of the hip muscles on the bony muscle attachments, which can exert competing forces against fractured bone segments and pull them out of alignment. Thus, healing of the fracture in a misaligned position is considered as a complication for intertrochanteric fractures. Intertrochanteric fractures may be further grouped into stable and unstable fractures, depending on the location, number, and size of the fractured bony segments [68].

3. Subtrochanteric fractures occur in the zone about 5 *cm* below the lesser trochanter of the proximal femur. The blood supply to the bone of the subtrochanteric region is not as good as the blood supply to the bone of the intertrochanteric region, and thus subtrochanteric fracture heals more slowly [68]. Similar to the intertrochanteric fractures, subtrochanteric fractures are likely to cause femur misalignment [68].

In more complicated cases, the fracture of the bone can involve more than one of these zones. **Figure 3** shows different types of proximal femur fracture.

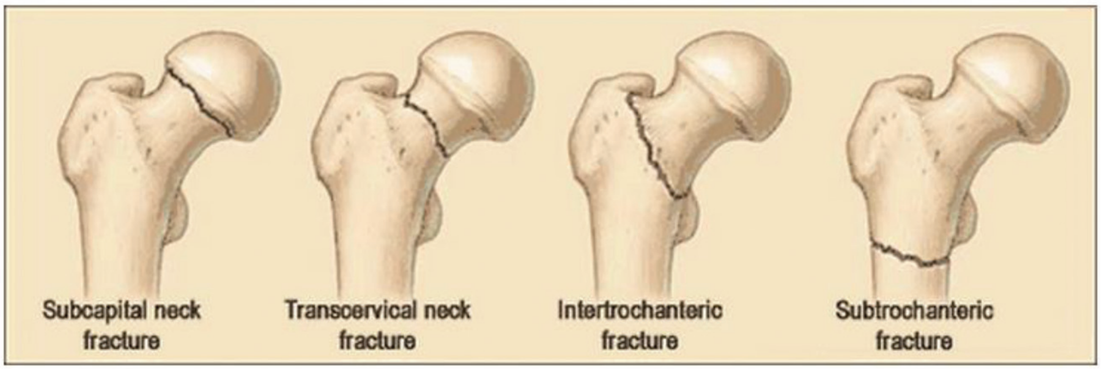

Figure 3. Three main types of hip fractures: femoral neck fracture (subcapital and transcervical fractures), intertrochanteric fracture, and subtrochanteric fracture [69].

6. Demographic feature of hip fractures

A variety of studies have examined hip fracture rates in different regions of the world [10, 51, 52, 70]. Greater than tenfold differences have been found on the basis of studies undertaken at a regional or national level for different calendar years. The studies show that the main demographic risk factors for hip fractures include increased age and female gender [10, 25]. The geographic distribution by fracture risk is shown for men and women combined in **Figure 4**. Heterogeneity in hip fracture risk in countries can be seen in this figure. Based on statistical results [10], for women, the lowest annual incidences are found in Nigeria (2/100,000), South Africa (20), Tunisia (58), and Ecuador (73). The highest rates were observed in Denmark (574/100,000), Norway (563), Sweden (539), and Austria (501). The incidence of hip fracture in men is approximately half of that noted in women. The highest annual incidence in men has been found in Denmark (290/100,000) and the lowest in Ecuador (35/100,000) [10].

As it is shown in **Figure 4**, the high-risk countries are Iceland, the United Kingdom, Ireland, Denmark, Sweden, and Norway in Northwestern Europe; Belgium, Germany, Austria, Switzerland, and Italy in Central Europe; Greece, Hungary, Czech Republic, Slovakia, and Slovenia in southwestern Europe; Lebanon, Oman, Iran, Hong Kong, Singapore, Malta, and Taiwan in Asia; and Argentina in South America. Regions of moderate risk include North America, Oceania, the Russian Federation, and southern countries of Latin America. Low-risk regions include the northern regions of Latin America, Africa, Jordan, Saudi Arabia,

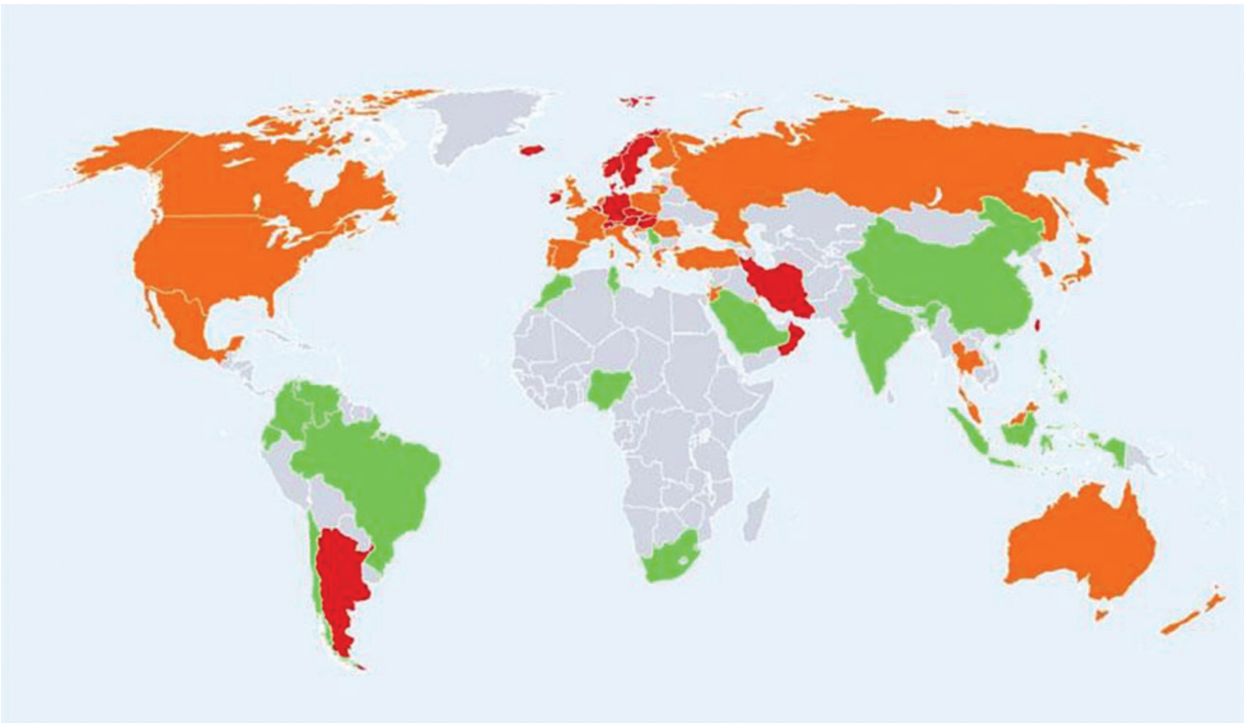

Figure 4. Hip fracture rates (men and women combined) in different countries of the world categorized by risk. Where estimates are available, countries are color-coded red (annual incidence >250/100,000), orange (150–250/100,000), or green (<150/100,000) [10] (reproduced with permission).

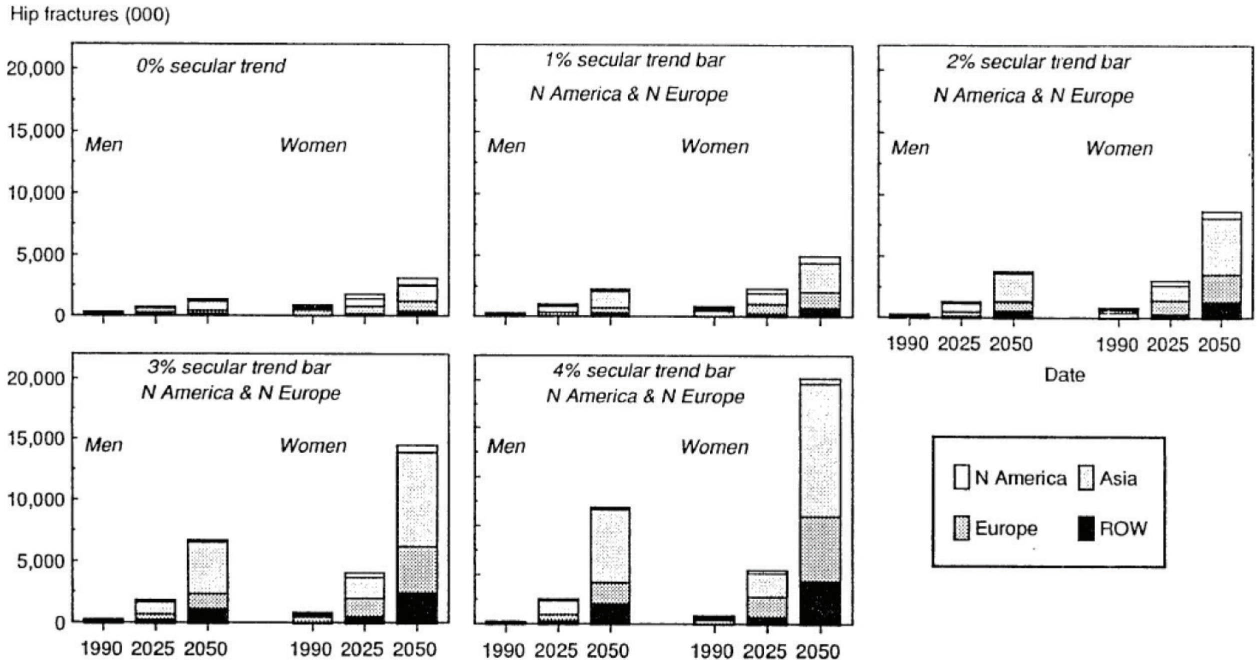

Figure 5. Estimated number of hip fractures by sex in the year 1990 and the number expected in 2025 and 2050 by region assuming no increase in age- and sex-specific rates, a 1% annual increase worldwide, or no increase in North America and northern Europe but an increase in age- and sex-specific incidence elsewhere of 2, 3, or 4%. (ROW is rest of world) [25] (reproduced with permission).

India, China, Indonesia, and the Philippines. It is notable that in Europe, the majority of countries are categorized as high or moderate risk. Low risk is identified only in Croatia and Romania [10].

Hip fracture incidence rates are known to increase exponentially with age in both men and women for the most regions of the world [71–74]. The increasing rate of hip fracture in the elderly is mainly associated with their slower reflex response and the inability to effectively use their arms to reduce the energy of the fall and low bone density of the proximal femur [44, 45].

Epidemiological studies show that the number of hip fractures will rise from 1.66 million in 1990 to 4.5–21.3 million by 2050 (**Figure 5**) depending on the underlying assumptions about age- and gender-specific incidence trends [9, 25, 51, 75].

7. Significance of accurately assessing hip fracture risk

The aim of accurately assessing hip fracture risk is to identify patients at high risk of hip fracture and to start intime prevention and protection measures to reduce the number of hip fractures. These measures are accepted by the patients only after they are accurately diagnosed with the high fracture risk. Also, accurate assessment of hip fracture risk is the prerequisite step before starting a therapy. For example, during the process of osteoporosis treatment, it is required to monitor the change of fracture risk and subsequently track the effectiveness of the therapy. By knowing the risk of fracture, people can improve their bone health and change their environment to reduce the likelihood of the fall.

Patients diagnosed with high fracture risk may consider the following prevention measurements:

- Individualized exercise programs:
  - Muscle-strengthening exercises [76]
  - Practicing balance exercises [77]
  - Increasing the lower extremity joint function [32]
- Management of visual impairment:
  - Obtaining maximum vision correction [6, 78]
- Examination of basic neurological function, including mental status, muscle strength, lower extremity peripheral nerves, and reflexes [79]
- Using mobility assisting devices (e.g., walking stick, frames)
- Implementing surveillance and observation strategies

Protection measurements must be provided to patients with high fracture risk, for example:

- Remembering that sideways falling is more likely to result in a hip fracture than falling in other directions [8]:
  - Trying to fall forward or backward not from sides
- Taking steps to reduce the potential energy and subsequently decrease the risk of fracture [80]
- Landing with the aid of hands or rea`chable objects around to break the fall [81]
- Using hip protectors [82–87]
- Environmental modification (e.g., flooring) [31]
- Medication and nutritional improvement:
  - Consuming a calcium-rich diet that provides about 1000 mg (milligrams) daily for men and women up to age 50 [88]. Women over age 50 and men over age 70 should increase their intake to 1200 mg daily from a combination of foods and supplements.
  - Obtaining 600 **IU** (international units = 0.025 μg) of vitamin D daily up to age 70 [88]. Men and women over age 70 should increase their uptake to 800 **IU** daily.
  - 5–15 min' exposure to sunlight 4–6 times per week [89].

8. Bone fracture criterion and hip fracture risk measurement

From biomechanics point of view, assessment of hip fracture under stance loading or lateral impact force has been performed using three criteria: factor of safety (FOS) [90], risk factor

(RF) [70], and fracture risk index (FRI) [91]. In this section, a review is performed on previously adopted bone fracture criteria in both 2D and 3D FE models.

Keyak et al. [90] assessed FOS under two loading conditions: one representing loading during the stance phase of gait and the other simulating the impact from a fall. Their study was based on a 3D FE model generated from CT data of the patient. They calculated FOS to compare the actual element strength with the applied von Mises stress.

Schileo et al. [92] applied maximum principle strain, von Mises stress, and maximum principle stress criteria to calculate risk factor and to predict fracture location of the femur. RF compares the applied stress/strain with the yield one to predict the bone fracture. Lotz et al. [93, 94] also used von Mises stress yield criterion for the cortical bone and crushing-cracking stress criterion for the trabecular bone. The performance of nine stress- and strain-based failure theories in assessment of hip fracture is investigated by Keyak and Rossi [95]. They evaluated the distortion energy (DE), maximum normal stress, maximum normal strain, maximum shear strain, maximum shear stress, Coulomb-Mohr, modified Mohr, Hoffman, and strain-based Hoffman failure theories, using CT-based FE models of the femur [95].

The abovementioned fracture risk measurements are all derived from CT images. The most recent DXA-based fracture risk criterion is proposed by Luo et al. [91]. They calculated the averaged FRI as a ratio between the effective stress (von Mises stress) by applied forces and the allowable stress (yield stress) of the bone over a region of interest (ROI). FRI is a local fracture risk measurement, while FOS and RF are global ones.

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Conflict of interest

Masoud Nasiri Sarvi declares that he has no conflict of interest.

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